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1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	911218	Final 881001 910930

4. TITLE AND SUBTITLE

Acoustic Studies of New Materials: Quasicrystals, Low-Loss Glasses, and High T_c Supersonductors

5. FUNDING NUMBERS

N00014-85-K-0701

6. AUTHOR(S)

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DTIC ELECTE DEC 1991 S C D

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Office of Naval Research
Physics Division, Code 1112
Arlington, VA 22217-5000

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

91-18860

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approaved for public release:
Distribution unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The goals of this project involve the development and application of new techniques in acoustics. The goals are: a) to study the properties of single crystal high temperature superconductor oxide materials with ultrasonic measurements; b) to study the properties of quasicrystals using ultrasound and acoustic analog systems; and c) to develop and apply a new resonant photo-acoustic technique to measure optical absorption in very low-loss glasses and crystals. Major accomplishments include the development of a new method of ultrasound measurement which permits the determination of all of the independent elastic constants of very small samples (a few hundred microns in size), the use of the apparatus to study high temperature superconductor material and aluminum alloy quasicrystals, and the development and test of a new technique for measuring optical absorption with more than an order of magnitude improvement in sensitivity over existing methods.

14. SUBJECT TERMS

15. NUMBER OF PAGES 26

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED.	UNCLASSIFIED	

NSN 7540-01-280-5500

Standard Form 298 (Rev 2-89)
Prescribed by ANSI Std Z39-18
298-102

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ACOUSTIC STUDIES OF NEW MATERIALS:

QUASICRYSTALS, LOW-LOSS GLASSES, AND HIGH Tc SUPERCONDUCTORS

I. INTRODUCTION

This report summarizes the goals and accomplishments for ONR contract N00014-85-K-0701, Mod P0004, "Acoustic Studies of New Materials: Quasicrystals, Low-loss Glasses, and High T_c Superconductors." The goals of the project involved the development and application of new techniques in acoustics. The goals were: a) to study the properties of single crystal high temperature superconductor oxide materials with ultrasonic measurements; b) to study the properties of quasicrystals using ultrasound and acoustic analog systems; and c) to develop and apply a new resonant photoacoustic technique to measure optical absorption in very low-loss glasses and crystals. The report lists published papers, submitted papers, talks, etc., and technical progress. Major accomplishments include a rigorous test of the small sample resonant ultrasound technique for measuring all of the elastic constants of very small samples of superconductors and quasicrystals, the use of the apparatus to study a high temperature superconductor material and an aluminum alloy quasicrystal, and measurements of optical absorption in very low loss optical materials using our new resonant photoacoustic technique. A list of our publications, presentations, honors, etc., are presented in appendices.

A complete list of publications, talks, etc. is presented in Appendix I. To summarize, there were three invited review papers on our research with quasicrystals and acoustic holography, and a total of 13 publications in refereed journals, including three in the prestigious Physical Review Letters; two additional papers have been accepted for publication, and three book chapters will be published in a forthcoming edition of the Physical Acoustics series and in the forthcoming Acoustics Handbook. An article featuring our quasicrystal research appeared on the front page of the New York Times Science Section (September 5, 1990). A number of invited talks describing our research were given: there were 31 invited colloquia at universities, national meetings, and research labs; there were also 16 contributed papers. During the period of the grant, the principal investigator was elected a member of the Acoustical Society of America and the American Physical Society, and was awarded the title of Distinguished Professor at the Pennsylvania State University. Three students received Master's degrees, and four students received their Ph.D. Abstracts from the theses are presented in Appendix II. Two postdoctoral research associates were supported during the grant period.

II. RESEARCH WITH THE SMALL-SAMPLE RESONANT ULTRASOUND TECHNIQUE

The small-sample resonant ultrasound technique was developed[1-6] for the purpose of measuring the elastic constants of new materials, which for one reason or another are available only in small samples, on the order of a few hundred microns in size. For such small samples, measurement with a conventional pulse-echo method[7] would involve great difficulties with transducer bonding, ringing and loading, parallelism of sample faces, beam diffraction, very short pulse generation and detection, and remeasuring to obtain a complete set of elastic constants. Our technique overcomes these difficulties by using very thin piezoelectric film (9 μm PVDF)[8] for transducers (instead of conventional quartz or lithium niobate) and by measuring a spectrum of acoustic resonances of the sample (instead of the conventional pulse-echo measurement of sound speeds) to determine the elastic constants. In our measurement technique, the sample, rather than the transducer, resonates, and so acts as its own natural amplifier with a gain equal to the quality factor (Q) of the resonance. The thin transducers are broadband (nonresonant) and for resonant measurement need be only weakly coupled to the sample, so that bonding and loading are not critical. The only difficulty in the technique lies in the long numerical calculation required to convert the measured resonant frequencies to the desired elastic constants; however, one of the most important features is that all of the independent elastic constants may be determined with a single measurement.[1-6]

A drawing of the current apparatus is shown in Fig. 1. The transducers are centered on narrow strips of piezoelectric film, tensioned between spring contacts. The sample is held by tension between a drive and receive transducer. In order to drive as many different modes as possible, the transducers contact the sample at low symmetry points, such as corners or edges; this also provides the advantage of having the transducer weakly coupled. The drive transducer is excited with a frequency synthesizer, and the signal from the receiver is monitored with a high frequency, low-noise preamp and lock-in detector.

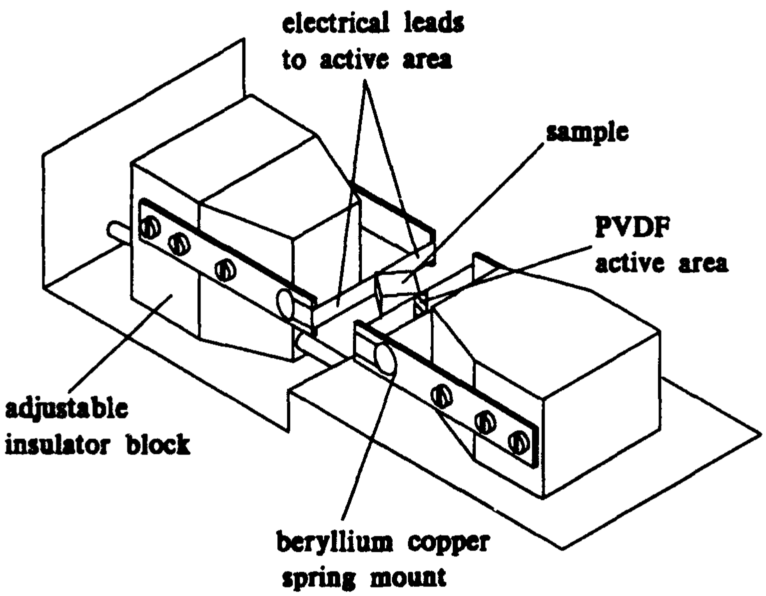

Fig. 1. Drawing of the current small-sample resonant ultrasound apparatus

To date, the small-sample resonant ultrasound apparatus has been tested with a ~500 µm sample of crystalline quartz,[5] and has been used to measure the elastic constants of a high temperature superconductor material (La_2CuO_4)[3] and a high quality sample of an aluminum alloy quasicrystal. For the quartz sample, our measured elastic constants were in good agreement with the reported constants (although there is some spread in the tabulated values); however, our sample was considerably smaller than any of the others used for measurements by the traditional ultrasonic pulse-echo technique. In the course of the testing we developed improved computer algorithms for inverting the measured acoustic spectrum to obtain the elastic constants. The results of the measurements on the aluminum alloy quasicrystal are quite recent. A sample was obtained from AT&T Bell Labs, and it required several months of careful polishing before a good single crystal was obtained. The room temperature resonant frequency spectrum for this sample is shown in Fig. 2; there are about 30 sharp resonances. Analysis of this data, currently in progress, will readily

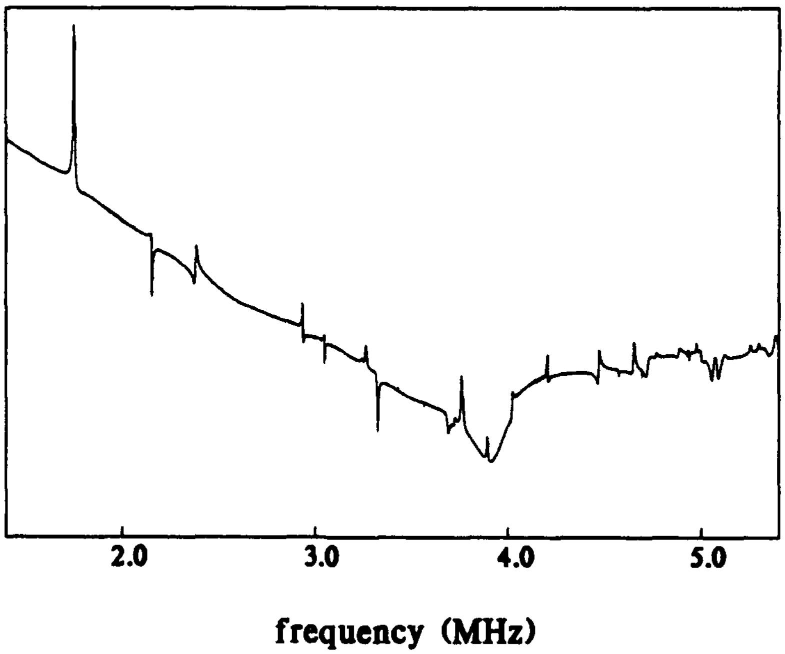

Fig. 2. Resonant frequency spectrum for the aluminum alloy quasicrystal

determine whether the elastic tensor is that of a true quasicrystal, or that of a BCC structure with a large icosahedral unit cell mimicking five-fold rotational symmetry. This data is probably the best which has been obtained for a quasicrystal. These results will be submitted to Phys. Rev. Lett. as soon as the analysis is complete.

III. THE RESONANT PHOTOACOUSTIC TECHNIQUE

One of the acoustic innovations under development in our research program is a resonant photoacoustic technique for measuring optical absorption in highly transparent crystals and glasses. Such highly transparent materials are important for applications in optical fiber long distance transmission lines, in lenses and windows for high-power laser systems, and in electro-optic, magneto-optic, and acousto-optic components for optical computers, etc. The optical absorption in new materials is so small that it has become difficult to measure in conveniently sized (~1 cm) samples. One of the most sensitive methods for measuring optical absorption is the photoacoustic technique,[9,10] which usually requires a high power pulse laser. Our resonant photoacoustic technique uses a continuous (CW) laser which has less power than a pulse laser, but nevertheless has orders of magnitude improved sensitivity in measuring optical absorption. This technique may be used to measure optical absorption coefficients as small as 10^{-8} cm^{-1}.[11]

The difference between the conventional photoacoustic technique and the resonant photoacoustic technique is illustrated in Fig. 3. In the conventional technique (Fig. 3a), a high power laser pulse, containing several hundred mJ of energy, passes through a sample, and the energy absorbed generates an acoustic pulse; the acoustic pulse is detected with a piezoelectric transducer attached to the sample. The amount of optical energy which was absorbed may be determined from the amplitude of the acoustic pulse. The sensitivity of the

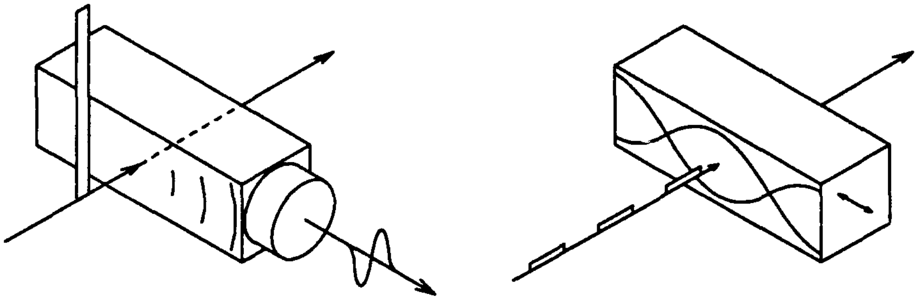

Fig. 3. Illustration of the conventional pulse (a) and new resonant (b) photoacoustic techniques

technique is limited by the noise (electrical, thermal) in the acoustic transducer.

In the resonant photoacoustic technique (Fig. 3b), the pulse laser is replaced with a continuous wave (CW) laser, which may have less power by a factor of 1000. However, the CW laser may be modulated at a frequency corresponding to an acoustic resonance of the sample, and when driven at resonance, the sample itself acts as a natural amplifier with a gain equal to the quality factor (Q) of the resonance. This gain occurs before the transduction, so that the transducer noise is not amplified. Since highly transparent samples are often made with high purity material, such samples will also have high mechanical Q's, at least 10^4 and as high as 10^6. The gain which arises by driving the sample at a high Q resonance more than compensates for the lower laser power, and results in ~100 times improved sensitivity. Furthermore, with CW modulation, very low noise phase sensitive detection may be employed.

The original test of the resonant photoacoustic technique involved measurements with a high quality (highly transparent) crystalline quartz sample. With this sample it was discovered that the dominant transduction mechanism was piezoelectric rather than dielectric. The transducer was an interdigital capacitor located in proximity to, but not touching, the sample;

the motion of the (dielectric and possibly piezoelectric) sample due to the acoustic field could be detected by the change in the transducer capacitance due to the moving dielectric, or by the voltage induced by the fringing electric field of the piezoelectric sample. For the quartz sample the piezoelectric mechanism gave a relative large signal. For a complete test of the technique it would be necessary to use a sample material which was not so piezoelectric. For this purpose James White has performed measurements using a high quality (highly transparent) CaF_2 sample. The signal is approximately two orders of magnitude smaller, but the absorption coefficient of ~10^{-4} cm^{-1} can still be measured.

In order to measure even smaller optical absorption coefficients, it is necessary to use a high power infrared laser. An equipment proposal for such a laser and related equipment was submitted to ONR and approved. The laser has been installed and will be used in future research.

IV. RESEARCH WITH LINEAR AND NONLINEAR ACOUSTIC ANALOGS

Studies of the effects of linear wave propagation in one-dimensional random systems have been pursued with some computer simulations which allow studies under much more diverse conditions than permitted with the mass-loaded wire experiment. The purpose was to explore the relevance of many of the theoretical statements which are made in regard to solid state systems. It was found that many of the statements are misleading. The problem is that the theory is limited to ensemble averages, while measurements are made on single realizations of a system, and there is no "ergotic theorem" for these effects. Another problem is that it is sometimes overlooked that Bloch waves are not real waves; they do not carry momentum and energy like real waves, and the fact that frequencies and wavenumbers must be equal does not mean that "energy" and "momentum" are being conserved. In fact is possible for a Bloch wave traveling in one direction to carry energy in the opposite direction. While theoreticians in solid state know this, semantics used for expedience have often led to confusion.

Experiments on nonlinear effects in the mass-loaded wire have been initiated. We have observed that for finite amplitude transverse waves, the arc length of the displaced wire is increased over the length of the equilibrium (straight) wire with the result that the tension in the wire is modulated. At sufficiently large amplitudes, the modulated tension in the wire parametrically excites other modes, with dramatic results. Results have been reported at the Acoustical Society meeting at Penn State University and at the ONR Principal Investigator meeting in Monterey. The nonlinear research will be pursued for a random system. A new type of experiment on mode-locking in a quasicrystalline system is being designed.

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A new resonant photoacoustic technique for measuring very low optical absorption in crystals and glasses

APPENDIX I

PAPERS SUBMITTED TO REFEREED JOURNALS
(Not yet published)

1. J. D. Maynard, "Using Piezoelectric Film and Acoustic Resonance to Determine the Complete Elastic Tensor in One Measurement", J. Acoust. Soc. Am., accepted for publication

2. C. Yu, M. J. McKenna, J. D. White, and J. D. Maynard, "A new resonant photoacoustic technique for measuring very low optical absorption in crystals and glassses", J. Acoust. Soc. Am., accepted for publication

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1. S. Kumar and J. D. Maynard, "Experimental Observation of the Layering and Wetting of Multilayer Liquid Helium-4 Films on Graphite", Phys. Rev. B 37, 7352 (1988) [Partial support by NSF DMR 8701682]

2. J. D. Maynard, "Acoustic holography for wideband, odd-shaped noise sources", Proceedings of Inter-Noise 88 (Institute of Noise Control Engineering, New York)

3. S. He and J. D. Maynard, "Eigenvalue spectrum, density of states, and eigenfunctions of a two-dimensional quasicrystal", Phys. Rev. Lett. 62, 1888, (1989)

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12. J. D. Maynard, "Tuning up a quasicrystal", in Mathematics of Random Media, ed. W. E. Kohler and B. S. White (American Mathematical Society, Providence, 1991) p.375-389

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1. J. D. Maynard, "Acoustical analogs for solving condensed matter problems", in Physics News in 1988, Phys. Today 42, S5 (1989)

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1. NSF Final Progress Report, 1989

2. Tania Slawecki, M.S. Thesis
   Measuring fourth sound in silica aerogel

3. Chang Yu, Ph.D. Thesis
   A high Q resonant photoacoustic technique for small optical absorption measurements

4. Yanmin Huang, Ph.D. Thesis
   Computer techniques for three-dimensional source radiation

5. J. A. Mather, M.S. Thesis
   A New Technique for Ultrasound Measurement in Very Small Samples with Applications to Aluminum Alloy Quasicrystals

6. Shanjin He, Ph.D. Thesis
   Acoustic analog experimental study of the physical properties of one dimensional disordered systems and two-dimensional quasiperiodic systems

7. Doug Meegan, M.S. thesis
   Nonlinear Effects in Random and Quasiperiodic Systems

8. Tom Brosius, Ph.D. thesis
An Investigation of the Helium Four Solid/Superfluid Interface in the Presence of Small Quantities of Helium Three

BOOKS (AND SECTIONS THEREOF) SUBMITTED FOR PUBLICATIONS

1. J. D. Maynard, A. Migliori, and W. M. Visscher, "Ultrasonic measurements of elastic constants in single crystals of La_2CuO_4", to be published as a chapter in Ultrasonics of High-Tc and Other Unconventional Superconductors, ed. Moises Levy

2. J. D. Maynard, "Acoustical Holography", to be published as a chapter in Handbook of Acoustics, ed. M. J. Crocker (John Wiley and Sons, New York)

3. J. D. Maynard, "Phonons in Crystals, Quasicrystals, and Anderson Localization" to be published as a chapter in Handbook of Acoustics, ed. M. J. Crocker (John Wiley and Sons, New York)

INVITED PRESENTATION AT TOPICAL OR SCIENTIFIC/TECHNICAL SOCIETY CONFERENCES

1. Invited Lecture, Noise-Con 88, Purdue University, June 20, 1988 "Acoustic Holography for Wideband Noise Sources of Arbitrary Shape"

2. Invited Lecture, Department of Physics, Iowa State University, November 23, 1987, "Tuning-up a Quasicrystal", C. M. Soukoulis, host

3. Invited Lecture, Los Alamos National Lab, Thermal Physics Division, February 25, 1988, "Tuning-up a Quasicrystal", Greg Swift, host

4. Invited Lecture, IBM Research Center, Yorktown Heights, April 7, 1988 "Tuning-up a Quasicrystal", Richard Webb, host

5. Invited Lecture, Department of Physics, University of Delaware, "Tuning-up a Quasicrystal", James Mehl, host

6. Invited Lecture, Texas Instruments, Dallas, TX, "Tuning-up a Quasicrystal", James Luscombe, host

7. J. D. Maynard, J. H. Mather, S. Brown, and A. Migliori, "Use of thin PVDF film for measuring small single crystal samples of high temperature superconductors", Acoustical Society of America meeting, Honolulu, Hawaii, November, 1988

8. A. Migliori, S. Brown, Z. Fisk, E. Ahrens, J. D. Maynard, and J. H. Mather, "Resonant ultrasound measurements in intrinsic and superconducting copper-oxygen plane compounds", Acoustical Society of America meeting, Honolulu, Hawaii, November, 1988

9. J. D. Maynard, "Acoustic holography for wideband arbitrarily shaped noise sources", Acoustical Society of America meeting, Honolulu, Hawaii, November, 1988

10. J. D. Maynard, "Acoustic Anderson localization", SIAM Workshop on Random Media and Composites, Leesburg, Virginia, December, 1988

11. J. D. Maynard, "Tuning up a Quasicrystal", American Association of Physics Teachers, Bloomsburg University, April 14, 1989

12. J. D. Maynard, "Using Piezoelectric Film and Acoustic Resonance to Determine the Complete Elastic Tensor in One Dimension", May 22, 1989 Meeting of the Acoustical Society of America.

13. J. D. Maynard, "Education, Research, and Acoustic Levity: Miscellaneous Demonstrations", May 22, 1989 Meeting of the Acoustical Society of America.

14. J. D. Maynard, "Tuning up a Quasicrystal", June 7, 1989 Meeting of the Americal Mathematical Society, Blacksburg, VA

15. Colloquiuum, Department of Physics, University of Delaware, Sept 21, 1988 "Tuning up a quasicrystal", J. R. Beamish, host

16. Colloquiuum, Department of Physics, Wesleyan University, November 3, 1988, "Tuning up a quasicrystal", R. J. Rollefson, host

17. Colloquiuum, Department of Physics, Indiana University, November 30, 1988 "Tuning up a quasicrystal", Steve Girvin, host

18. Colloquiuum, Department of Physics, University of Massachussettes, Amherst, April 19, 1989, "Tuning up a Quasicrystal"; R. Guyer, host

19. Invited Lecture, IEEE Ultrasonics Symposium, October 1989, Montreal "Analog simulations of acoustic localization"

20. Invited Lecture, 1990 AAPT/APS Joint Meeting, Atlanta, GA, January 1990 "Classical acoustics solves quantum mechanical puzzles"

21. Invited Lecture, National Meeting of the American Association for the Advancement of Science, February 1990, New Orleans "Classical acoustics solves quantum mechanical puzzles"

22. Invited lecture (with David Blackstock) 119th Meeting of the Acoustical Society of America, State College, May 1990 "Demonstration of nonlinear acoustics phenomena"

23. Colloquium, Department of Physics, University of Houston, October 1989 "Tuning-up a quasicrystal"

24. Seminar, Exxon research and Engineering Company, November 1989 "Acoustic Anderson localization"

25. Colloquium, Department of Physics, Kent State University, February 1990 "Tuning-up a quasicrystal"

26. Colloquiuum, NASA Goddard Space Flight Center, March 1990 "Quasicrystals and impossible forms of matter"

27. Colloquium, Department of Physics, Ohio University, September 21, 1990 "Tuning-up a Quasicrystal"

28. Symposium Lecture, 120th Meeting of the Acoust. Soc. Am., San Diego, November 30, 1990, "Acoustic holographic reconstruction of arbitrarily shaped surfaces"

29. Symposium Lecture, 120th Meeting of the Acoust. Soc. Am., San Diego, November 30, 1990, "Acoustic analogs for solving problems in solid state physics".

30. APS March Meeting Symposium, Cincinnati, March 20, 1991, "Linear and nonlinear wave propagation in periodic and nonperiodic media".

31. Colloquium, Department of Physics, Case Western Reserve University, September 5, 1991 "Tuning-up a quasicrystal", Arnold Dahm, host

CONTRIBUTED PRESENTATIONS AT TOPICAL OR SCIENTIFIC/TECHNICAL SOCIETY CONFERENCES

1. J. D. Maynard and Shanjin He, "Eigenmodes of Quasicrystals", J. Acoust. Soc. Am. 82, S78 (1987), Miami, November 19, 1987

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6. C. Yu and J. D. Maynard, 118th Meeting of the Acoustical Society of America, St. Louis, November 1989, "A new resonant photoacoustic technique for measuring very low optical absorption in glasses"

7. J. D. Maynard and C. Yu, 118th Meeting of the Acoustical Society of America, St. Louis, November 1989, "The use of reciprocity to calibrate a resonant photoacoustic measurement"

8. T. M. Slawecki, M. J. McKenna, and J. D. Maynard, "Measurements of high frequency fourth sound in low density aerogel", Bull. Am. Phys. Soc. 35, 1027 (1990)

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11. M. J. McKenna, P. S. Spoor, R. L. Stanley, and J. D. Maynard, "Experiments on linear and nonlinear wave propagation in random and quasiperiodic media" 119th Meeting of the Acoustical Society of America, State College, May 1990

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15. J. D. White, C. Yu, M. J. McKenna, and J. D. Maynard, "Resonant photoacoustic measurements of very low optical absorption in piezoelectric and dielectric crystals", J. Acoust. Soc. Am. 89, 1910 (1991).

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HONORS/AWARDS/PRIZES

Elected Fellow of the American Acoustical Society, November 18, 1988

Elected Fellow of the American Physical Society, November 12, 1989

Awarded the title of Distinguished Professor of Physics at the Pennsylvania State University, January 11. 1991

An article featuring our research on quasicrystals appeared on the front page of the New York Times science Section, September 5, 1989.

GRADUATE STUDENTS SUPPORTED UNDER CONTRACT N00014-85-K-0701

1. Yanmin Huang (Ph.D. candidate, physics) [Summer support 1988-1990]
   Computer Techniques for Unbaffled Source Radiation

2. Shanjin He (Ph.D. candidate, physics) [Summer support 1988-1990]
Acoustic Anderson Localization

3. Tom Brosius (Ph.D. candidate, physics) [Partial support by NSF] 1988-1990
Wave Propagation and Flow of Superfluids in Random Media

4. Chang Yu (Ph.D. candidate, physics) 1988-1990
Acousto-optic Resonance

5. Jim Mather (MA candidate, physics) 1988
Ultrasound Velocity and Attenuation in Quasicrystals

6. Ping Wang (PhD candidate, physics) 1988-1990, currently on leave
Ultrasound Velocity and Attenuation in High Temperature Superconductors

6. Tania Slawecki (M.S. candidate, physics) 1989
Ultrasound measurements in Superfluid Filled Aerogels

7. Philip Spoor (Ph.D. candidate, acoustics) 1990-1991
Elastic Constants for Aluminum Alloy Quasicrystals and High Tc Superconductors

8. Doug Meegan (M.S. candidate, physics) 1990-1991
Nonlinear effects in Random and Quasiperiodic Systems

9. James White (Ph.D. candidate, physics) 1990-1991
Infrared Resonant Photoacoustic Technique

10. Vern Hopkins (Ph.D. candidate, physics) 1991
NMR measurements for 3He at the 4He quantum solid/liquid interface

11. Wei-Li Lin (Ph.D. candidate, physics) 1991
Infrared resonant photoacoustics

POSTDOCTORALS SUPPORTED UNDER CONTRACT FOR YEAR ENDING 30 SEPTEMBER 1991

1. Dan Finetello, Research Associate, [Partial Support, 1988]

2. Mark McKenna, Research Associate, began July 1, 1989

APPENDIX II

The Pennsylvania State University

The Graduate School

Department of Physics

Measuring Fourth Sound in Silica Aerogel

A Thesis in

Physics

by

Tania Maria Slawecki

Submitted in Partial Fulfillment

of the Requirements

for the Degree of

Master of Science

December 1989

Abstract
Measuring Fourth Sound in Silica Aerogel
Tania Maria Slawecki
M.S.; December 1989
The Pennsylvania State University
Julian D. Maynard, Jr., Thesis Advisor

The properties of superfluid ^{4}He are well documented so that it becomes convenient to use this non-viscous liquid to probe the structure of porous media. The recent development of aerogels introduces a new porous material whose interesting properties directly relate to their microstructures. Measuring fourth sound in silica aerogel reveals a definite deviation in the fourth sound speed and attentuation as a function of temperature. This difference is attributed to the scattering correction n, which is directly related to the geometry of the silica network. However, n is also found to vary with temperature. This deviation may be due to the high compressibility of the aerogel, which no longer acts as a rigid frame for clamping the normal fluid component.

The Pennsylvania State University

The Graduate School

Graduate Program in Physics

A High Q Resonant Photoacoustic Technique for Small Optical Absorption Measurements

A Thesis in

Physics

by

Chang Yu

Submitted in Partial Fulfillment
of the Requirements
for the Degree of

Doctor of Philosophy

ABSTRACT

A new photoacoustic (PA) technique has been developed for measuring small optical absorption in highly transparent materials. In this new technique, the laser intensity is modulated at the acoustic resonant frequency of the solid sample, to obtain an enhanced PA signal and therefore an improved measurement sensitivity.

Experiments testing this new technique were carried out on crystalline quartz (SiO_2) samples having ~ centimeter dimensions. A significant amplification of the PA signal proportional to Q (quality factor) is observed when the laser intensity is modulated at the resonant frequency (~ 10^5 Hz) of the quartz sample. To increase the Q and thus increase the sensitivity, the measurements are carried out in vacuum, the sample supports are located at nodal lines of the resonance with computer controlled positioners, and the transducers are non-contact interdigital capacitors fabricated by a photolithography technique. The best Q thus obtained was close to one million (0.84×10^6).

The non-contact transducers not only eliminate the problem of background signals due to scattered light, they also allow measurements on a sample without requiring any modification of or attachment to the sample.

At a CW laser power of ~ 1W and wavelength of 514.5 nm, a PA signal as high as 50 μV was obtained at the sample resonance with a signal-to-noise ratio of 1000, for an

absorbed optical energy of 10^{-10} J per cycle. The optical absorption coefficients of the quartz samples have been determined by this PA technique.

To explore the possibility of further improvements in the measurement sensitivity, multiple laser beam pass experiments have been performed and the PA signal was found to increase significantly with the increasing number of laser beam passes.

The Pennsylvania State University

The Graduate School

Department of Physics

COMPUTER TECHNIQUES
FOR THREE-DIMENSIONAL SOURCE RADIATION

A Thesis in

Physics

by

Yanmin Huang

Submitted in Partial Fulfillment
of the Requirements
for the Degree of

Doctor of Philosophy

May 1990

ABSTRACT

A zoom imaging computer algorithm is presented, which can be used to compute the directivity of far-field radiation. Test cases demonstrate the success of this algorithm.

The Helmholtz Integral Equation method to compute the acoustical radiation of a three-dimensional source with arbitrary shape is reviewed. A numerical method to solve the Helmholtz Integral Equation using the finite element method is discussed. Second order interpolation functions, usually called shape functions, are used and they result in better accuracy and time saving in input data entry. Solutions for spherical monopole and dipole sources are compared to the theoretical results and agree well.

A new equivalent surface source method which is based on the Helmholtz Integral Equation is developed. It gives improved accuracy and can be used to compute the field of high frequency sources as well.

The Singular Value Decomposition (SVD) method is employed in these computer techniques. The uniqueness problem related to the surface Helmholtz Integral Equation can be monitored, and SVD can also be used to compute the eigenvalues of the corresponding interior problem. Some test results are presented.

The singular value decomposition method coupled with the finite element method implementation of Helmholtz Integral Equation enabled us to extend the near-field acoustical holography technique from two-dimensional to three-dimensional sources. Hence enabled us to reconstruct the motion on the surface of three-dimensional source from the measured acoustical field.

Reconstruction from numerical test case and near-field acoustical holography experiments are presented. The results are in good agreements with theoretical predictions.

The Pennsylvania State University

The Graduate School

Department of Physics

A New Technique for Ultrasound Measurement in Very Small Samples with Applications to Aluminum Alloy Quasicrystals

A Paper in Physics

by James H. Mather

Submitted in Partial Fulfillment
of the Requirements
for the degree of

Master of Science

May 1990

ABSTRACT

Well developed ultrasonic techniques exist for measuring acoustic properties of macroscopic samples. Recently, however, a number of interesting materials have been discovered which are only available in the form of very small samples. Of particular interest here is the quasicrystal. The largest pure quasicrystalline samples to date are only on the order of a few hundred microns in diameter. We have developed an ultrasonic resonance technique to study the acoustic properties of these small samples using a polymer piezoelectric film called polyvinylidene fluoride (PVDF). We have also worked with preparing the samples and have taken some preliminary data with the ultrasonic apparatus on $T_2(Al_6CuLi_3)$ (a quasicrystalline material) as well as on quartz.

The Pennsylvania State University

The Graduate School

Department of Physics

Acoustic Analog Experimental Study of Effects of Anderson Localization in One Dimension and Physical Properties of Two Dimensional Quasiperiodic Systems

A Thesis in

Physics

by

Shanjin He

Submitted in Partial Fulfillment
of the Requirements
for the Degree of

Doctor of Philosophy

August 1990

ABSTRACT

In this thesis, experimental study of the effects of Anderson localization in a one-dimensional random system and of physical properties of a two-dimensional quasiperiodic system by using acoustic analog techniques is reported.

The acoustic simulation experiment of Anderson Localization involves a one-dimensional wave medium consisting of a long steel wire. The wave field analogous to the electron Schrodinger wave consists of transverse waves in the wire generated with an electromechanical actuator. The Bloch-wave behavior is verified with the masses spaced periodically. In the study of localization effects, the positions of the masses are varied. Several sets of measurements are made with the positions randomly varied within maximum displacements from lattice sites of 1%, 2%, and 5% of the lattice constant.

Inelastic scattering effects in the localization problems is studied with 2% spacing disorder. In this investigation, two eigenstates are selected as an initial state and a final state. The transverse actuator is driven at the initial-state eigenfrequency, and a longitudinal actuator is driven at the frequency for resonant phonon-assisted hopping. The response of the system is then measured as a function of the amplitude of the longitudinal strain modulation amplitude. The measured hopping probability as a function of the longitudinal drive amplitude is obtained.

The acoustic simulation experiment to investigate the physical

properties of quasicrystals involved coupled oscillators in a two dimensional Penrose lattice. The tight-binding model is used and the tuning forks mounted at the centers of the rhombuses of the Penrose tile as local oscillators are nearest-neighbor-coupled together with arcs of steel wire connecting the tines of neighboring tuning forks. The oscillations of the system is driven by an electromagnet. The responses of the system is monitored by electrodynamic transducers. The eigenvalue spectrum, determined as a composite of the resonant spectra from 20 different positions in the Penrose pattern, shows a feature resulting from the quasiperiodic symmetry: the spectrum has gaps and bands whose widths are in the ratio of the Golden Mean $(\sqrt{5}+1)/2$. The eigenfunctions of the system are obtained which show the motions of the quasiperiodic oscillator system (both amplitude and polarization) at eigenfrequencies.

The Pennsylvania State University

The Graduate School

LINEAR AND NONLINEAR THIRD SOUND IN NONUNIFORM POTENTIAL FIELDS

A Thesis in

Physics

by

George Douglas Meegan, Jr.

Submitted in Partial Fulfillment
of the Requirements
for the Degree of

Master of Science

August 1991

Abstract

Recently, there has been interest in linear and nonlinear wave propagation in nonuniform potential fields. This thesis describes such research using surface waves in absorbed superfluid helium, which should show strong local nonlinear behavior. These experiments include studies of linear and nonlinear third sound propagation in uniform as well as periodic perturbed quasi-one-dimensional media.

Both pulsed and continuous wave experiments have been conducted to study propagating waveforms, speeds of propagation as a function of drive levels, frequency versus response curves, and reflection coefficients as a function of drive level. These measurements have been made with drive levels varying over several orders of magnitude.

The results of these experiments exhibit nonlinear effects including a velocity of propagation which is dependent on drive level. We also find that the band structure which is observed for the periodic case is destroyed by the nonlinearity when drive levels are increased. However, another regular structure is observed at these higher drive levels.

A computational model of linear wave pulses in one-dimensional media was developed. This model uses a spectral technique and a theoretically derived third sound dispersion relation to study dispersion and attenuation effects. It was found that the third sound type of dispersion gives rise to a propagating waveform which is quite different from that resulting from more common types of dispersion.